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Combustion Engineering's Furnace Sorbent Injection Programs for SO2 Control

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COMBUSTION ENGINEERING'S FURNACE SORBENT INJECTION PROGRAMS FOR SO_2 CONTROL

by

R. W. Koucky
M. Rao Gogineni
J. L. Marion

COMBUSTION ENGINEERING, INC.
WINDSOR, CT 06095-0500

EPA Contract 68-02-4224

EPA Project Officer
Samuel L. Rakes

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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16. ABSTRACT The paper discusses three Combustion Engineering programs relating to the furnace sorbent injection process, a low-cost method for controlling sulfur dioxide (SO2) emissions from tangentially fired, coal burning boilers. The programs are: (1) pilot-scale investigations in the laboratory, (2) a prototype-scale program in a 65 MW utility boiler, and (3) a demonstration-scale program in a 180 MW utility boiler. A primary application of this technology is for retrofitting existing boilers in response to expected U.S. legislation for control of acid rain. In this process, the sorbent, usually calcium hydroxide (Ca(OH)2) or limestone (CaCO3), is injected above the flame zone where it mixes with flue gas containing SO2. The SO2 reacts chemically in the upper furnace with lime (CaO), formed from the sorbent, to make solid calcium sulfate (CaSO4). The CaSO4 is removed with fly ash in existing particulate control equipment.

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COMBUSTION ENGINEERING'S FURNACE SORBENT INJECTION PROGRAMS FOR SO_2 CONTROL

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INTRODUCTION

Combustion Engineering is developing furnace sorbent injection as a low-cost method for control of sulfur dioxide (SO_2) emission from coal-fired boilers. One primary application of this technology is for retrofit of existing boilers in response to expected U.S. legislation for control of acid rain.

The principles of furnace sorbent injection are shown in Figure 6-1. The sorbent, usually calcium hydroxide ($Ca(OH)_2$) or limestone ($CaCO_3$), is injected above the flame zone and mixes with flue gas containing SO_2. The SO_2 reacts chemically in the upper furnace with lime (CaO), formed from the sorbent, to make solid calcium sulfate ($CaSO_4$). Important design requirements are to provide effective mixing of the sorbent and to provide the greatest possible residence time in the sulfur capture temperature zone. The $CaSO_4$ is removed with fly ash in existing particulate control equipment.

Furnace sorbent injection is particularly well-suited for retrofit applications, where the SO_2 reduction requirements will likely be modest compared to those for new sources. With furnace injection, the cost of SO_2 removal can be reduced by as much as 30 percent and the capital cost reduced by over $200/kW, relative to conventional flue gas desulfurization systems. When combined with humidification and low-temperature sorbent injection at the inlet to the particulate removal device for enhanced SO_2 removal, the economic comparison may be even more favorable toward sorbent injection. It is reasonable to expect 40 to 50 percent SO_2 reduction with furnace injection of $Ca(OH)_2$ and up to 60 percent or more when both furnace injection and back-end injection with humidification are used.

Combustion Engineering has been involved in furnace sorbent injection for many years and is currently conducting three programs. These are:

- pilot-scale investigation in the laboratory
- prototype-scale program in a 65 MW utility boiler
- demonstration-scale program in a 180 MW utility boiler

This report discusses each of these programs.

PILOT SCALE PROGRAM

The pilot-plant scale program is being conducted under EPA

FURNACE SORBENT INJECTION

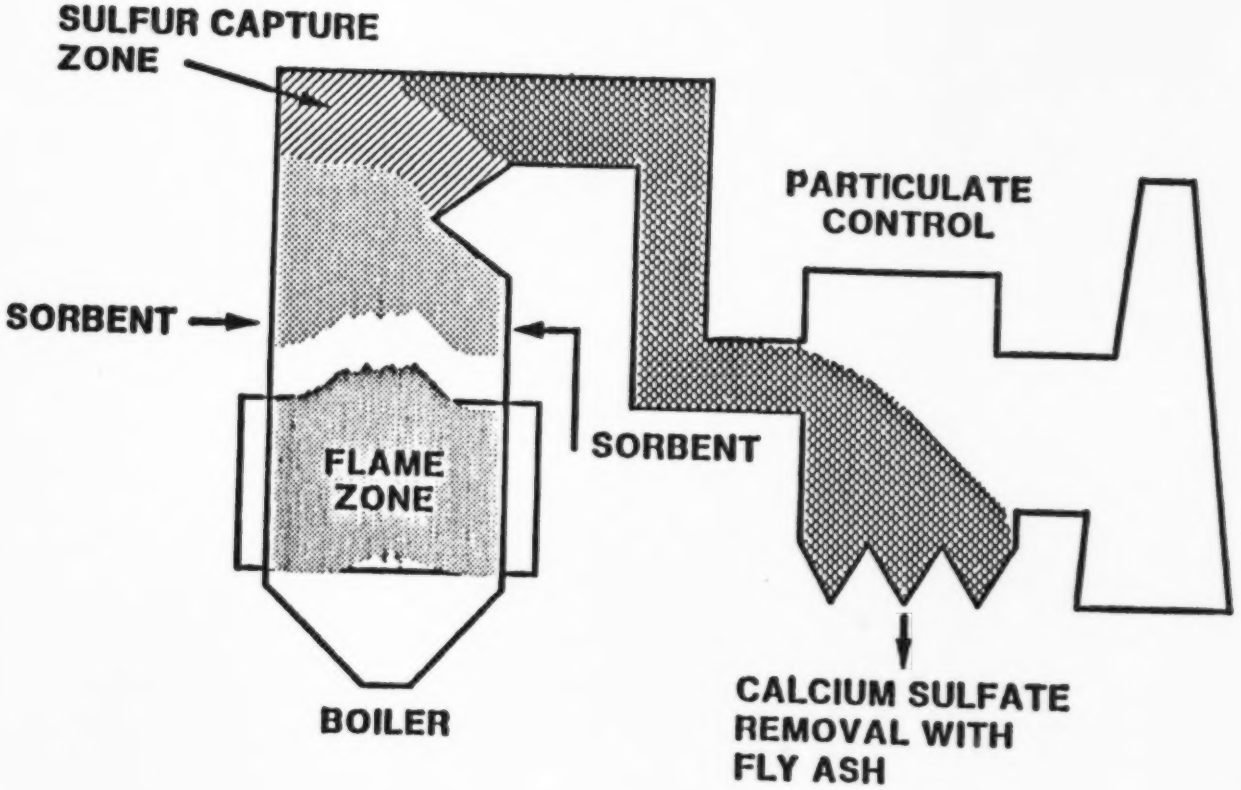


Figure 6-1

sponsorship at C-E's Kreisinger Development Laboratory (KDL) in Windsor, Connecticut, to develop criteria for the location and method of sorbent injection into tangentially fired coal-burning utility boilers in order to provide cost-effective removal of sulfur oxides. The program includes four tasks. The objectives of these tasks are:

Task A - Evaluate sorbent injection locations and methods in a cold-flow facility which simulates C-E's tangentially fired Boiler Simulation Facility (BSF).

Task B - Recommend sorbent injection locations and methods by applying mathematical modeling to Task A data with consideration of sorbent activation and residence time at sulfation temperature.

Task C - Test sorbent injection location/injector design combinations in the BSF.

Task D - Recommend sorbent injection system design criteria for a full-scale tangentially fired boiler demonstration.

Tasks A and B have been completed. Technical work is in progress on Task C, and work on Task D has begun. Tasks A, B, and C are discussed in the following sections.

Cold Flow Modeling Approach

Task A, cold flow modeling, consisted of three screening levels designed to lead to the selection of injector design/location combinations for combustion testing. In the first screening level, flow visualization tests of 16 configurations at simulated full load furnace operating conditions were conducted. Each configuration was evaluated at up to three injector carrier air velocities, for a total of 46 injection schemes.

The 11 best injector configurations from the first screening level were then evaluated in the second screening level, which consisted of three-dimensional velocity profile measurements and mixing studies using a methane tracer gas measured by a laser absorption spectrophotometer. In the third screening level, the five configurations which demonstrated the best performance in the second level testing were tested over a range of simulated furnace operating conditions using the same techniques utilized during the first two screening levels.

Experimental Method

Isothermal flow modeling was performed in the Large Scale Furnace Aerodynamics Test Facility (LSFATF) located at KDL (Figure 6-2). For this program, the facility was converted into a 0.46-scale simulation of the BSF. Built primarily of clear

LARGE-SCALE FURNACE AERODYNAMICS TEST FACILITY

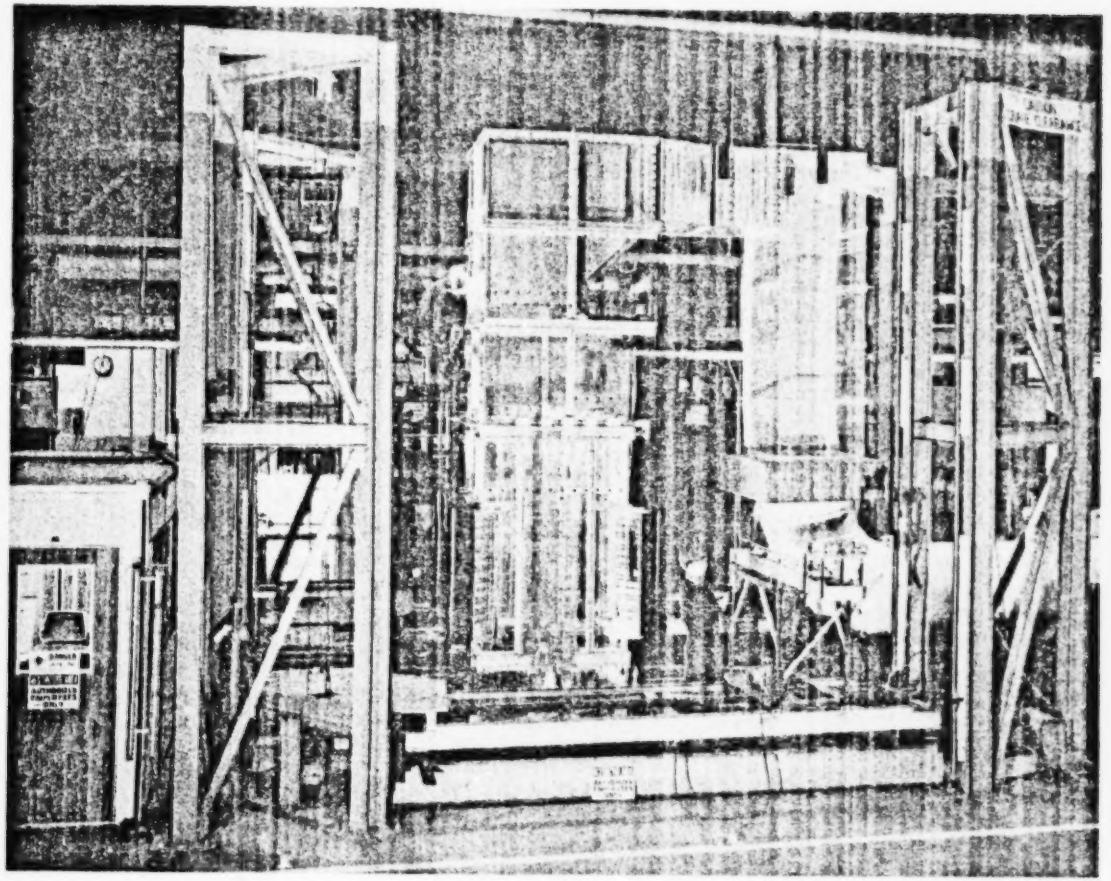


FIGURE 6-2

plastic, the model encompasses the entire furnace from the hopper to the economizer outlet. The windboxes are designed to permit adjustment of the tangentially fired fuel admission assemblies including tilt, offset, air staging, and overfire air. Upper furnace radiant and convective heat transfer surfaces are also modeled. A header system provides controlled introduction of smoke particles or tracer gas to any one or a combination of simulated sorbent injectors.

Surrounding the furnace model is a three-axis instrument traversing system which allows the placement of instrument packages, including a five-hole pitot tube, a laser doppler anemometer, and a laser absorption spectrophotometer.

Cold Flow Test Program

Past laboratory and pilot-scale sulfation experiments suggest that the optimum location for sorbent injection is in the region where the flue gas is in the range between 2200°F (1200°C) and 2400°F (1316°C). The optimum injection temperature varies with sorbent type, furnace quench rate, and other parameters. In addition, the optimum temperature location varies from boiler to boiler. Injector locations were selected to provide generalized design data for the full range of utility boilers. The locations and description of injector configurations are given in Table 6-1 and Figure 6-3.

Flow Visualization Test Results

Figure 6-4 is a photograph of a typical flow visualization test for injection from the front wall into the lanes between superheater panels. At high injection velocities, injection from the lowest elevation on the front wall (location A on Figure 6-3) gave good sorbent penetration and mixing within the upper furnace. However, the region above the arch was not adequately covered. This was corrected somewhat by tilting the nozzles downward 20°. This is detailed in Figures 6-5 and 6-6. The dispersion was further improved by increasing the injection velocity to a value greater than the simulated BSF injection velocity of 75 ft/sec (22.9 m/sec). For the injection locations higher on the front wall of the furnace, mixing was not as good as that observed for the lowest front wall location. Downward tilts from the upper injection locations improved sorbent penetration and mixing, but did not achieve the performance observed from injection at the lowest front wall position. However, for furnaces in which the sulfation temperature window begins after the first set of superheater panels, injection from the intermediate front wall location might be attractive.

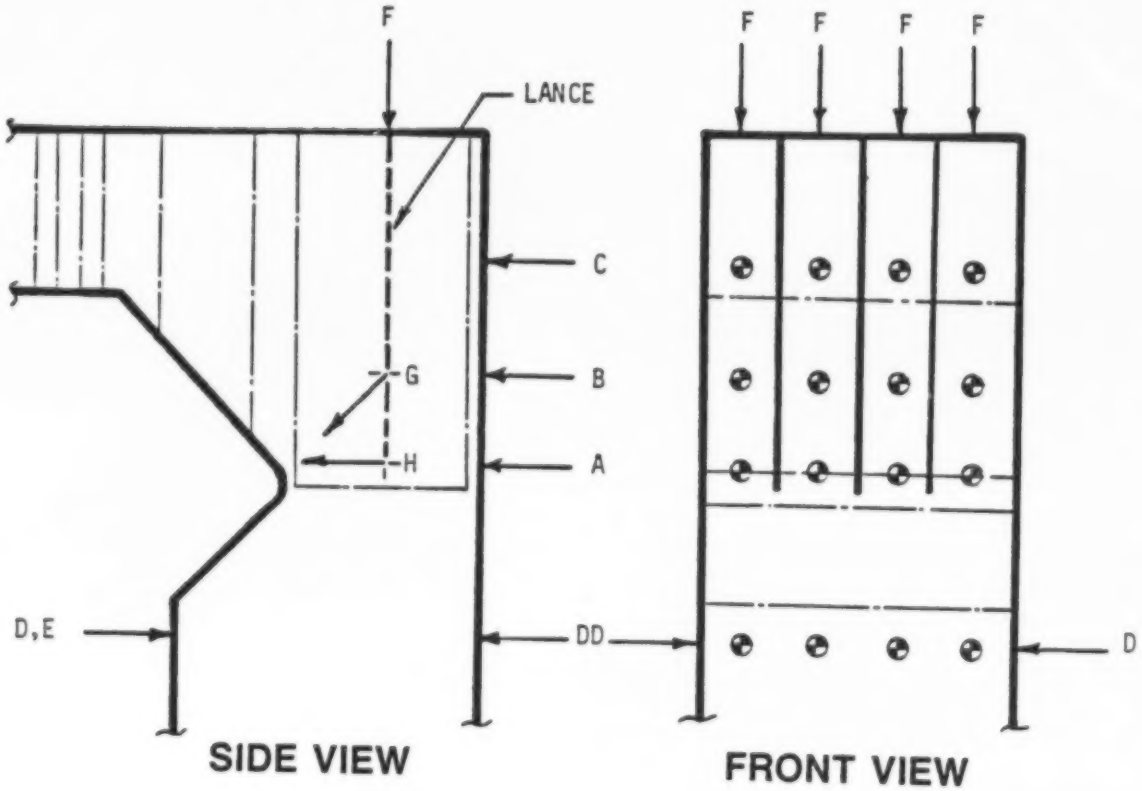
It was found from the flow visualization testing that 5 percent of the total BSF combustion air flow for sorbent carrier air was sufficient, and that higher injection velocities were preferred. For a given injection velocity, injection counter to

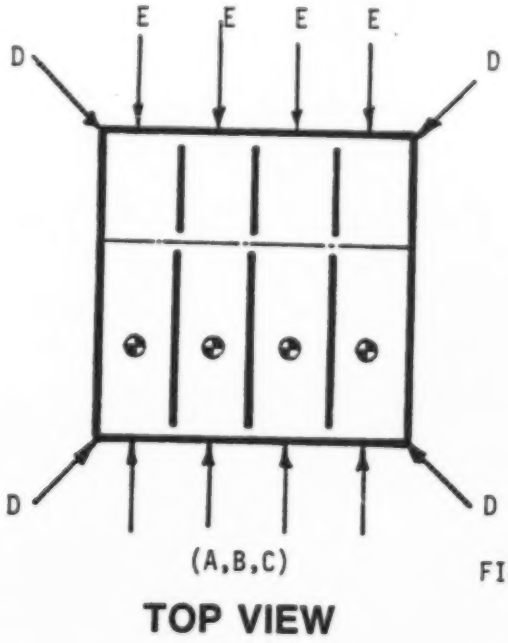
TABLE 6-1. FIRST SCREENING LEVEL TEST CONFIGURATIONS

Configuration*	Location	Description
1	A	Above arch, low, along front wall
2	B	Above arch, mid, along front wall
3	C	Above arch, high, along front wall, -45° tilt
4	A,B	Combination of Configurations 1 & 2
5	B,C	Combination of Configurations 2 & 3
6	A,C	Combination of Configurations 1 & 3
7	A,B	Combination of Configurations 1 & 2 Location A with high velocity Location B with low velocity
8	D	Under arch, T-fired corotational
9	D	Under arch, T-fired counter-rotational
10	E	Under arch, along back wall
11	E,B	Under arch, along back wall combined with above arch, along front wall
12	F	Roof mounted
13	A,F	Four above arch, low, along front wall with four roof mounted
14	H	Roof mounted, single port, vertical hanging lance, low position, and 90° tilt
15	G	Roof mounted, hanging lance, high position, and -45° tilt
16	H,C	Roof mounted, single port, vertical hanging lance, combined with front wall, high

* See Figure 6-3 for definition of locations

SORBENT INJECTION LOCATIONS





INJECTOR LOCATION ←

FIGURE 6-3

FLOW VISUALIZATION TEST OF
FRONT WALL INJECTION

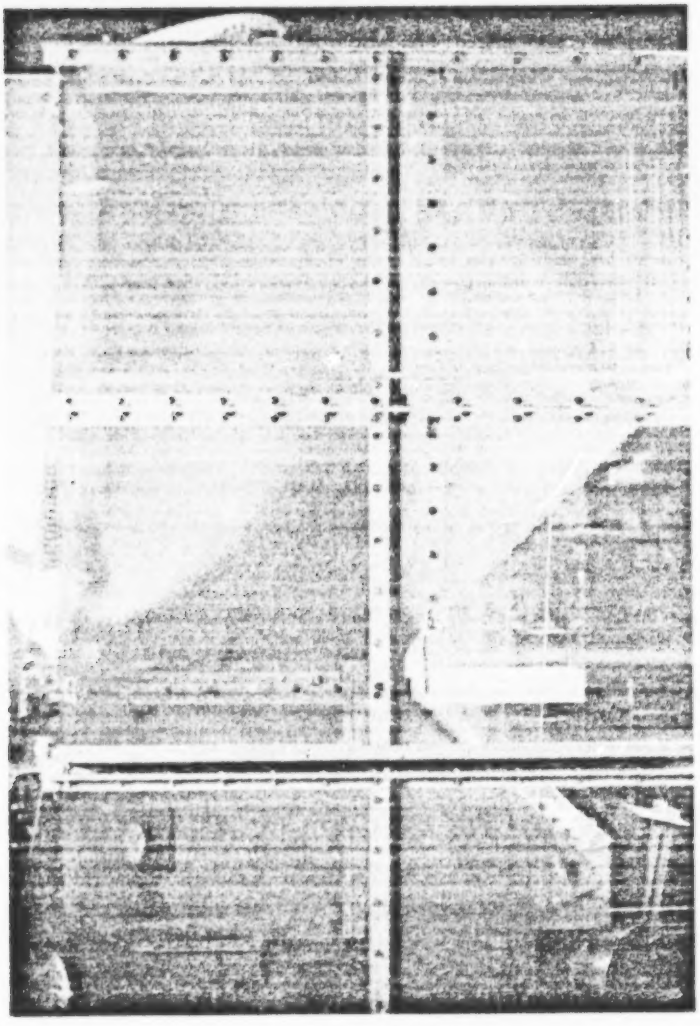


FIGURE 6-4

HORIZONTAL INJECTION
75 ft/sec (22.9 m/sec)

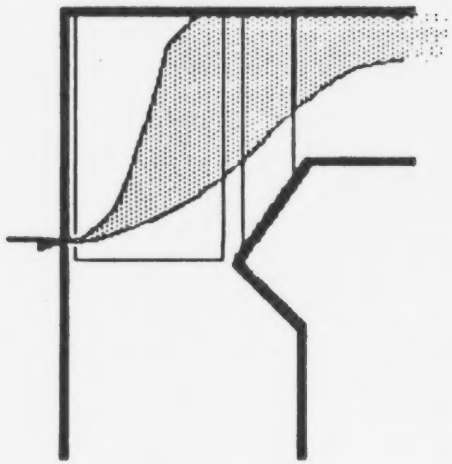


FIGURE 6-5

-20^{o} INJECTION
75 ft/sec (22.9 m/sec)

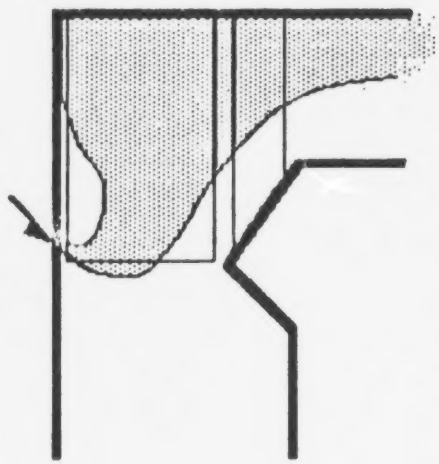


FIGURE 6-6

the local flow field provided better sorbent dispersion than perpendicular or co-directional injection, due to the enhanced turbulent mixing which such an injection scheme offers. Lances were found to provide precise positioning of the injection of sorbents and also the highest observed levels of dispersion when injected against the direction of the local flow field. While the nonsymmetric nature of the aerodynamics within the upper furnace did not greatly affect the observed performance of the injection systems tested, its effect was greatest for injection schemes involving injectors mounted on the front wall of the unit. Lastly, injection with eight injectors rather than four resulted in an overall reduction in sorbent dispersion for a given injection carrier air mass flow rate. Table 6-2 details the 11 injection configurations that, based on the flow visualization tests, provided the best overall sorbent penetration and dispersion. These configurations were advanced to the second screening level for mixing traverse testing.

Steady State Gas Mixing Tests

The purpose of the second screening level was to quantify the level of "sorbent" penetration and dispersion for the 11 best configurations selected form the first screening level. Two planes of steady state gas mixing data were obtained for each of the 11 injection schemes. The planes evaluated were the two closest test planes downstream of the actual point of injection. (See Figure 6-7 for locations of LSFATF test planes.) Mixing of solid sorbent particles was characterized by a tracer gas using scaling relationships. The tracer gas was introduced into the injector air flow at a point far enough upstream to ensure a uniform tracer gas concentration at the exit of the injector. Using a sampling probe attached to an Automatic Probe Traversing Device, the concentrations of tracer gas at specified locations within the furnace flow model were determined.

Figures 6-8 and 6-9 present typical results of tracer injection tests in the form of contour plots and isoconcentration plots (plots of constant concentration). The plotted concentrations are ratios of measured local concentration divided by the fully mixed concentration measured at the outlet of the model. The numerical values on the isoconcentration plots correspond to lines of constant concentration equal to 0.5, 1.0, 1.5, 2.0, etc. times the well mixed tracer gas concentration. Based on mixing effectiveness and the expected location of the sulfation temperature window at the BSF during Task C combustion tests, five injection configurations were selected for advancement to the third screening level. These are listed in Table 6-3.

TABLE 6-2. SECOND SCREENING LEVEL TEST CONFIGURATIONS

Test No.	Injectors	Location	BSF Injection Velocity ft/sec (m/sec)	Tilt	Description
201	4	F	75 (22.9)	0°	Roof straight down
202	4	G	75 (22.9)	-45°	Front facing lance
203	4	B	75 (22.9)	-20°	Front wall
204	4	A	75 (22.9)	-20°	Front wall
205	4	A	100 (30.5)	0°	Front wall
206	4	D	75 (22.9)	-20°	T-fired (counter)
207	4	E	75 (22.9	-20°	Rear wall
208	8	B/E	75/75 (22.9/22.9)	-20°/-20°	Front and rear wall
209	8	A/F	75/75 (22.9/22.9)	-20°/-20°	Front wall and roof
210	8	B/G	75/75 (22.9/22.9)	0°/0°	Front wall and roof lance
211	4	C	100 (30.5)	-20°	Front wall

BSF FLOW MODEL TEST PLANE LOCATIONS

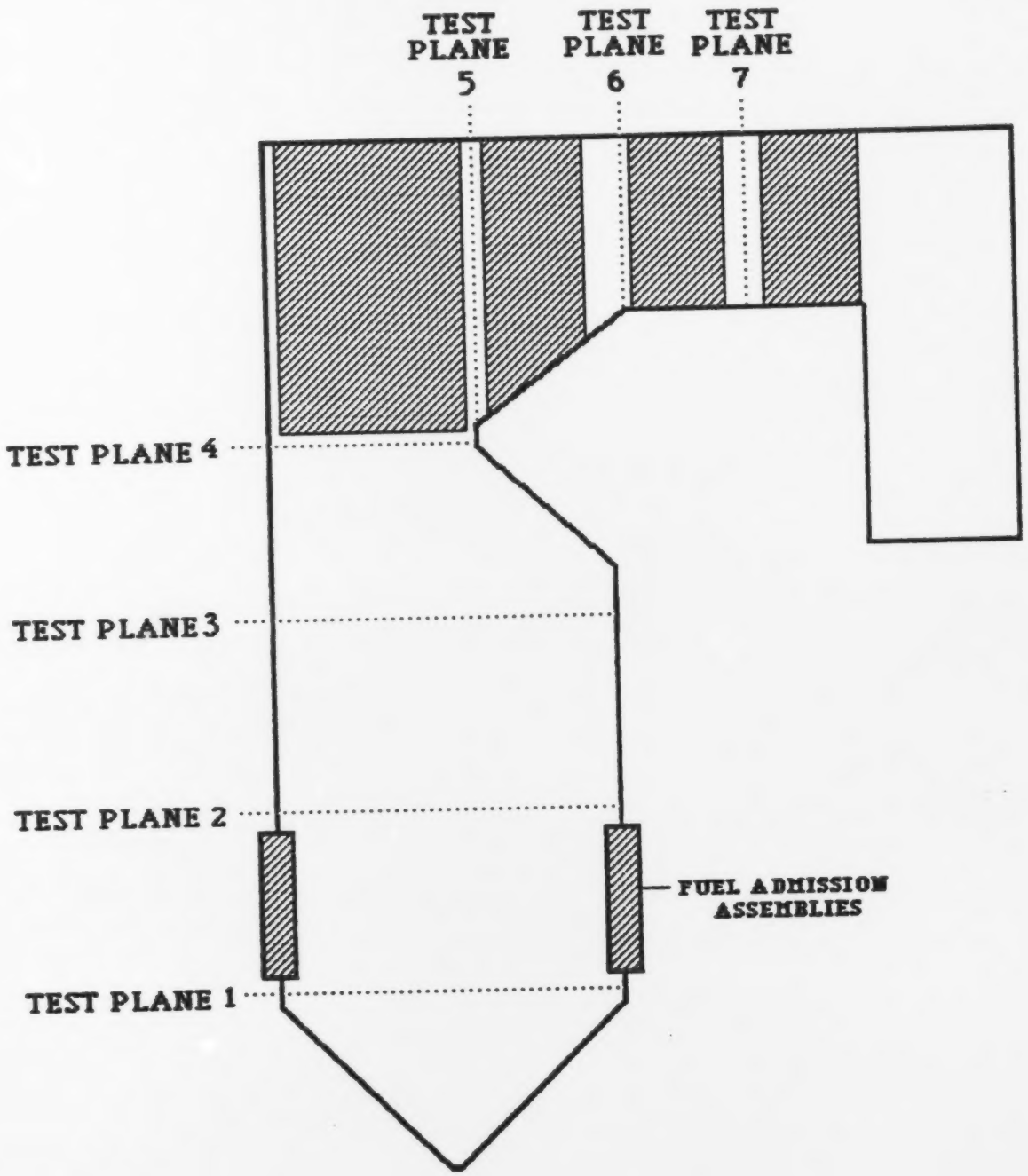
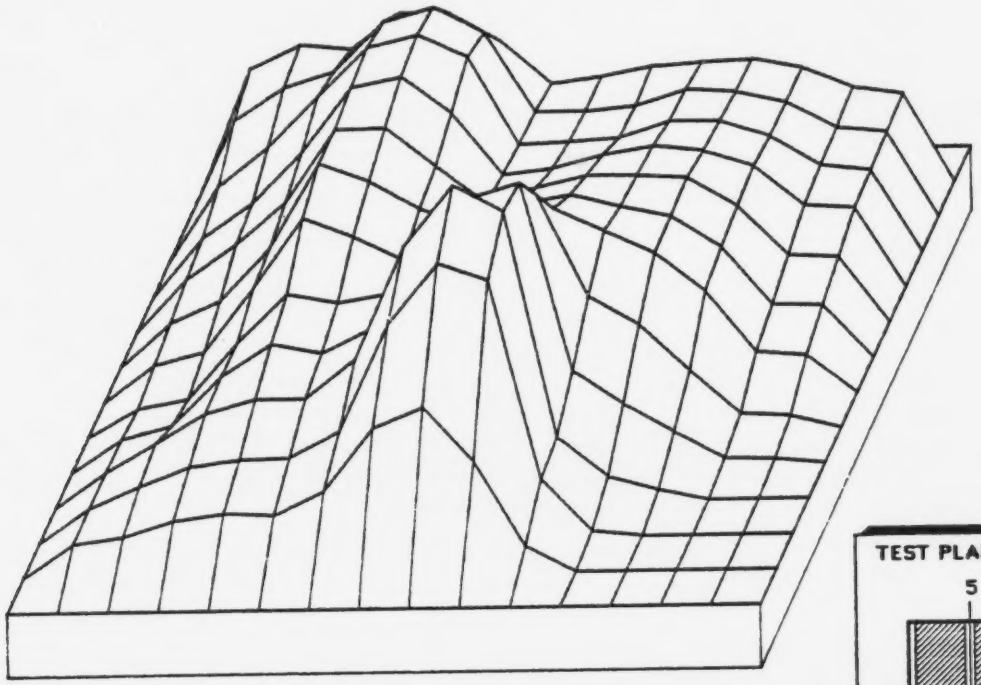
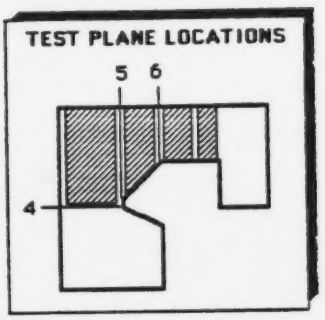


FIGURE 6-7

GAS MIXING ISOCONCENTRATION PLOT: TEST NO. 205: PLANE 5





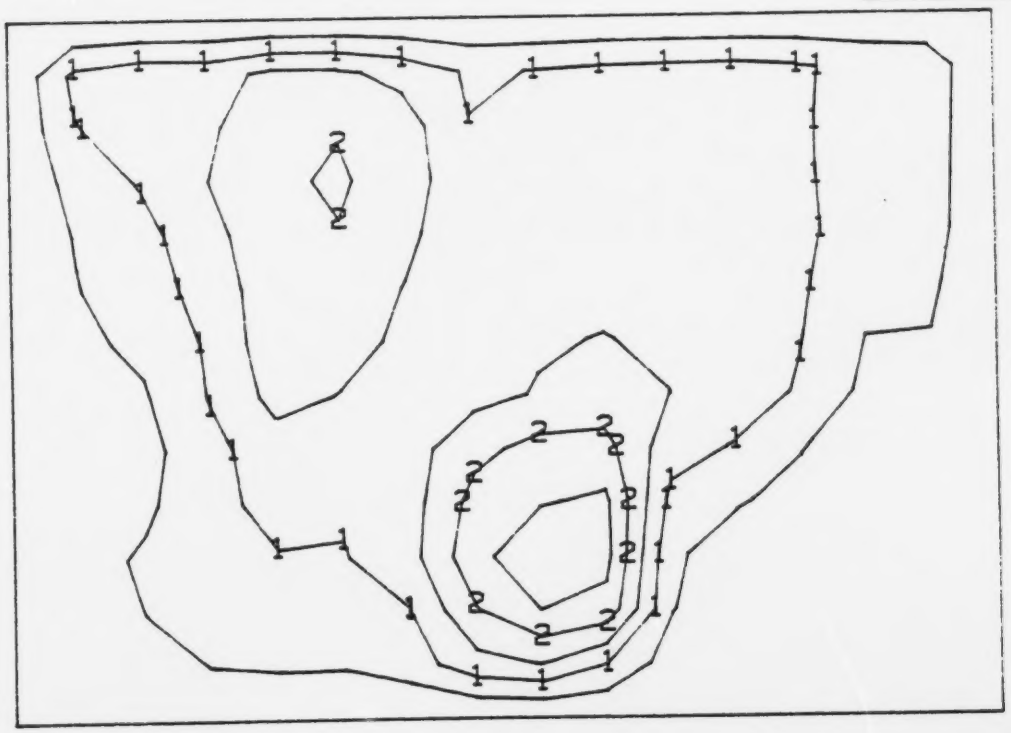


FIGURE 6-8

GAS MIXING ISOCONCENTRATION PLOT: TEST NO. 205: PLANE 6

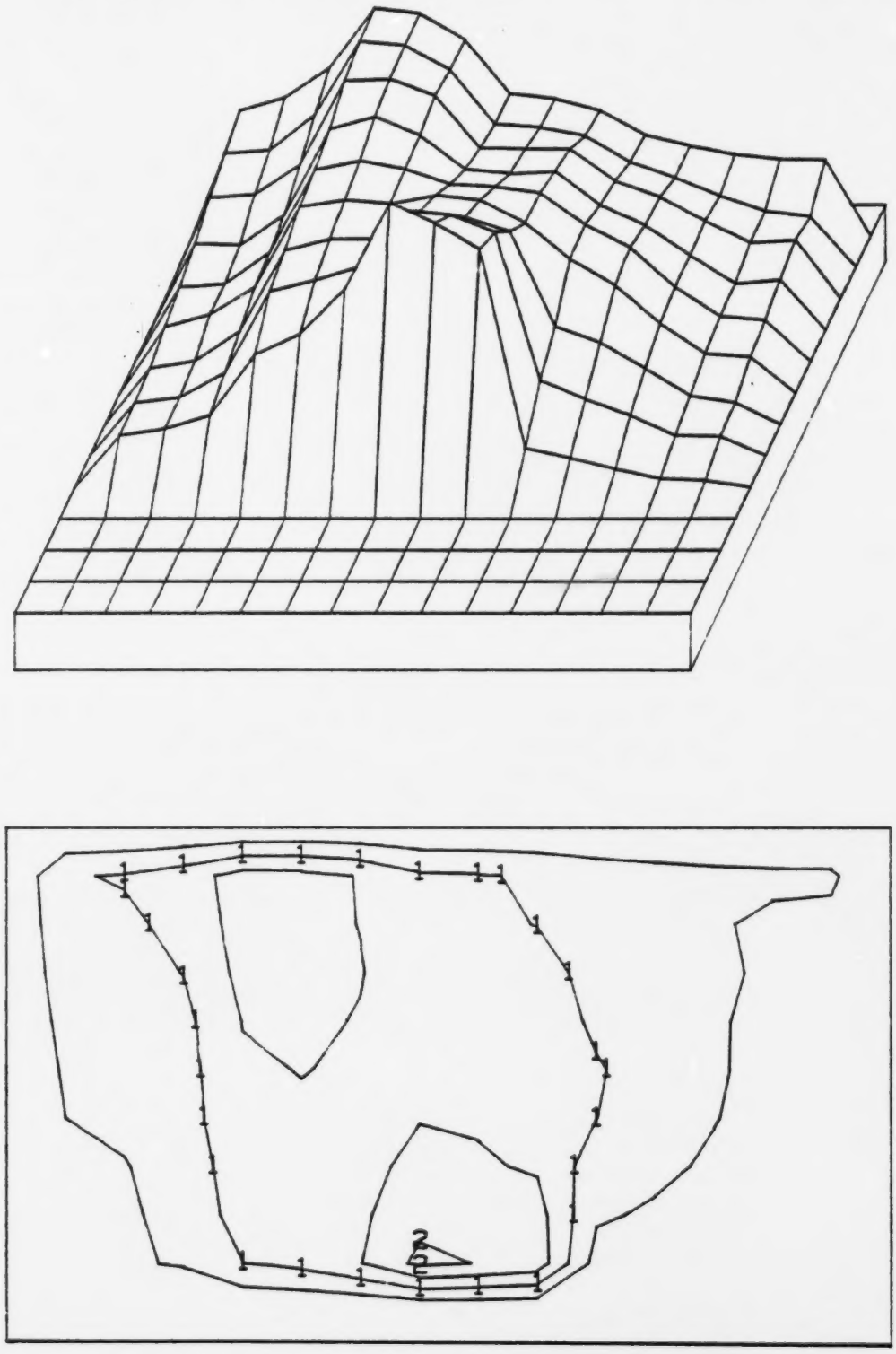


FIGURE 6-9

TABLE 6-3. THIRD SCREENING LEVEL CONFIGURATIONS

Test No.	Location	Tilt	Description
201	F	0°	Roof 75 ft/sec (22.9 m/sec)
202	G	180° (Upstream)	Front facing lance 75 ft/sec (22.9 m/sec)
204	A	-20°	Front wall low 75 ft/sec (22.9 m/sec)
205	A	0°	Front wall low 100 ft/sec (30.5 m/sec)
211	C	-20°	Front wall high 100 ft/sec (30.5 m/sec)

Burner Tilt Testing

Additional tests were performed on the configurations listed in Table 6-3 to evaluate the effect of fuel admission assembly tilt and the resulting changes to the upper furnace aerodynamics on the penetration and dispersion performance of the injection system. The tests consisted of additional three-dimensional velocity traverses and steady state gas mixing tests. In general, it was found that tilting the fuel admission assemblies either up or down 20° had little or no significant effect on the penetration and dispersion performance of the sorbent injection system.

Summary of Flow Modeling Results

A new jet modeling technique was developed which allows a two-phase jet issuing into a hot environment to be accurately modeled isothermally by a single-phase gas-only jet. Using this technique a large number of sorbent injection systems were evaluated in a multi-level screening process which systematically reduced the number of potential candidates. These tests were performed in a large-scale cold-flow model of the BSF.

Several of the injection systems evaluated provided high levels of sorbent dispersion within the flow model. A restricted number were recommended for the sulfation temperature window expected in the BSF. From the 46 initial injection schemes evaluated, 5 were recommended for Task C Combustion Testing in the BSF. The configurations, detailed in Table 6-3, were chosen based on their ability to provide effective sorbent dispersion within the anticipated BSF sulfation temperature window.

Task B - Mathematical Modeling

Mathematical modeling was conducted in two areas. One was thermal modeling to identify the preferred location in the furnace for sorbent injection and to provide furnace time/temperature profiles. The second was SO_2 capture performance modeling. This modeling, ultimately, will be used to make SO_2 capture performance predictions and performance guarantees. Over the shorter term, the modeling will be used to interpret test results and to provide recommendations for further development testing.

Task C - Combustion Testing

Combustion testing will apply sorbent injection techniques developed under Task A (Flow Modeling) and Task B (Mathematical Modeling) in the pilot-scale tangentially fired BSF operating at 50×10^6 Btu/hr (14.7 MW thermal). A number of injector design/location combinations will be tested over a range of furnace and injector operating conditions. Three sorbent types will be evaluated.

The BSF models the time/temperature history, heat release rate, heat absorption, and aerodynamic characteristics of a large utility boiler (Figure 6-10). All major aspects of a utility boiler are duplicated, including the lower furnace, the ash hopper, multiple burners, the arch section, superheater panels, and the convection heat transfer surfaces. The BSF is top-supported like a typical utility boiler.

The BSF is fully instrumented to monitor combustion phenomena. Access ports are located throughout the furnace and convective sections for temperature and velocity measurements, for particulate sampling, and for flue gas sampling. Optical access ports are also distributed at selected locations around the facility for visual observations.

Facility construction and commissioning tests have been completed. Sorbent injection performance testing began in April 1987. Two recent photographs of the facility in operation are shown in Figures 6-11 and 6-12.

PROTOTYPE PROGRAM

The tangentially fired sorbent injection prototype program will be conducted at the 65 MW Whitewater Valley Unit No. 2 of Richmond Power and Light in Richmond, Indiana. This unit was designed by Combustion Engineering. The program is sponsored by the U.S. Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI). C-E has a subcontract to Energy and Environmental Research Corporation, the prime contractor.

COMBUSTION ENGINEERING'S BOILER SIMULATION FACILITY (BSF)

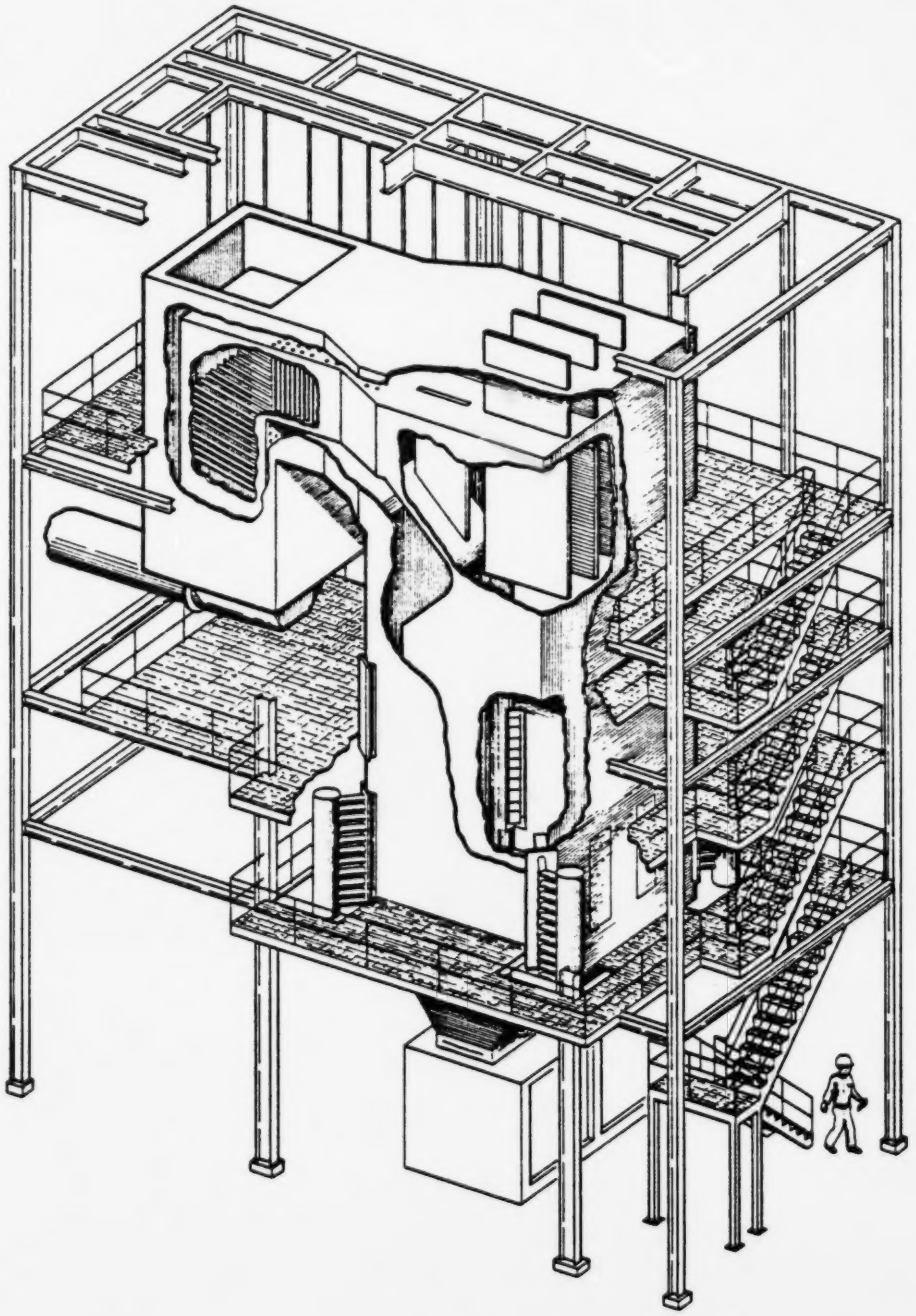


FIGURE 6-10

BSF IN OPERATION

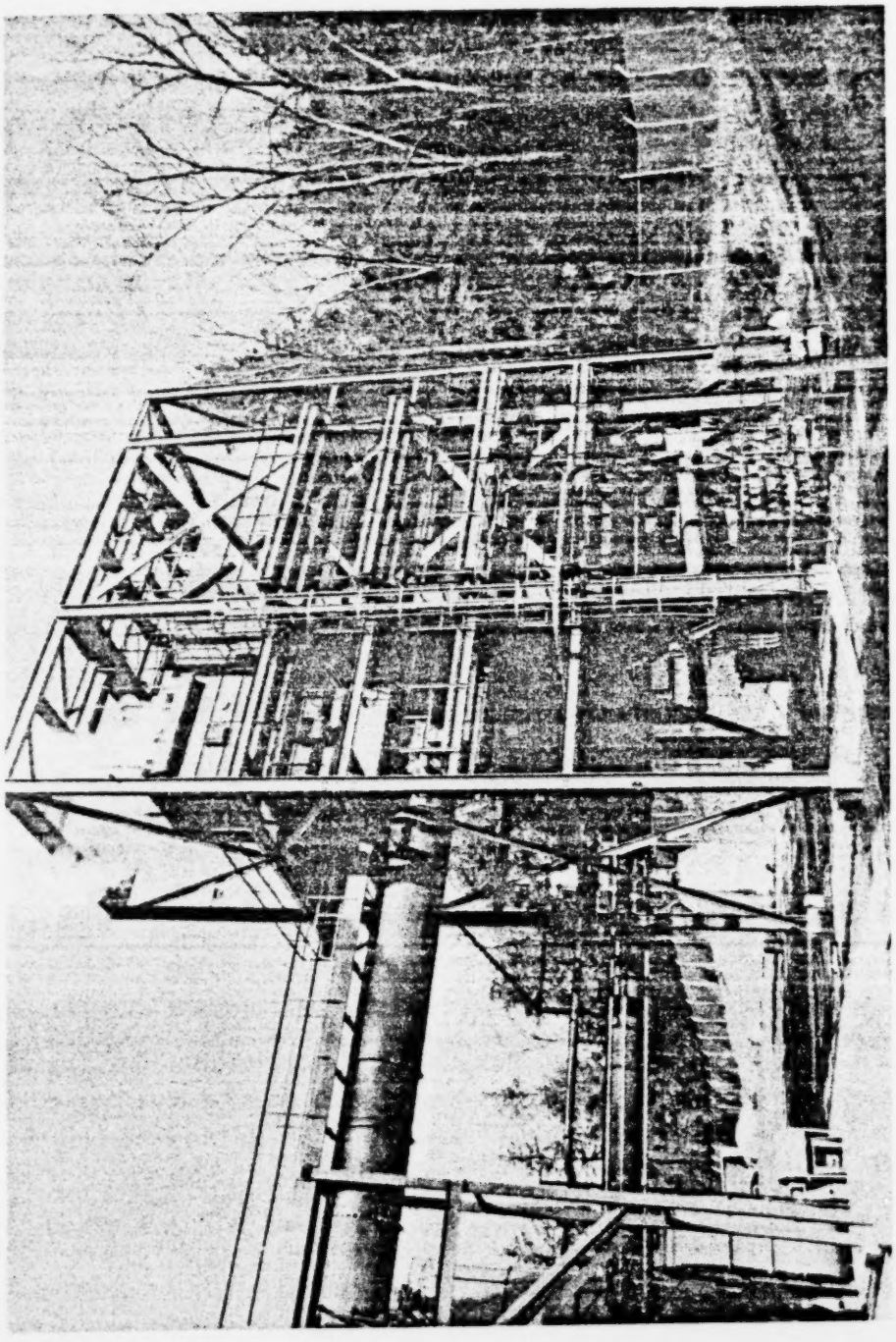


FIGURE 6-11

BSF OUTLET DUCT AND BACK-END EQUIPMENT

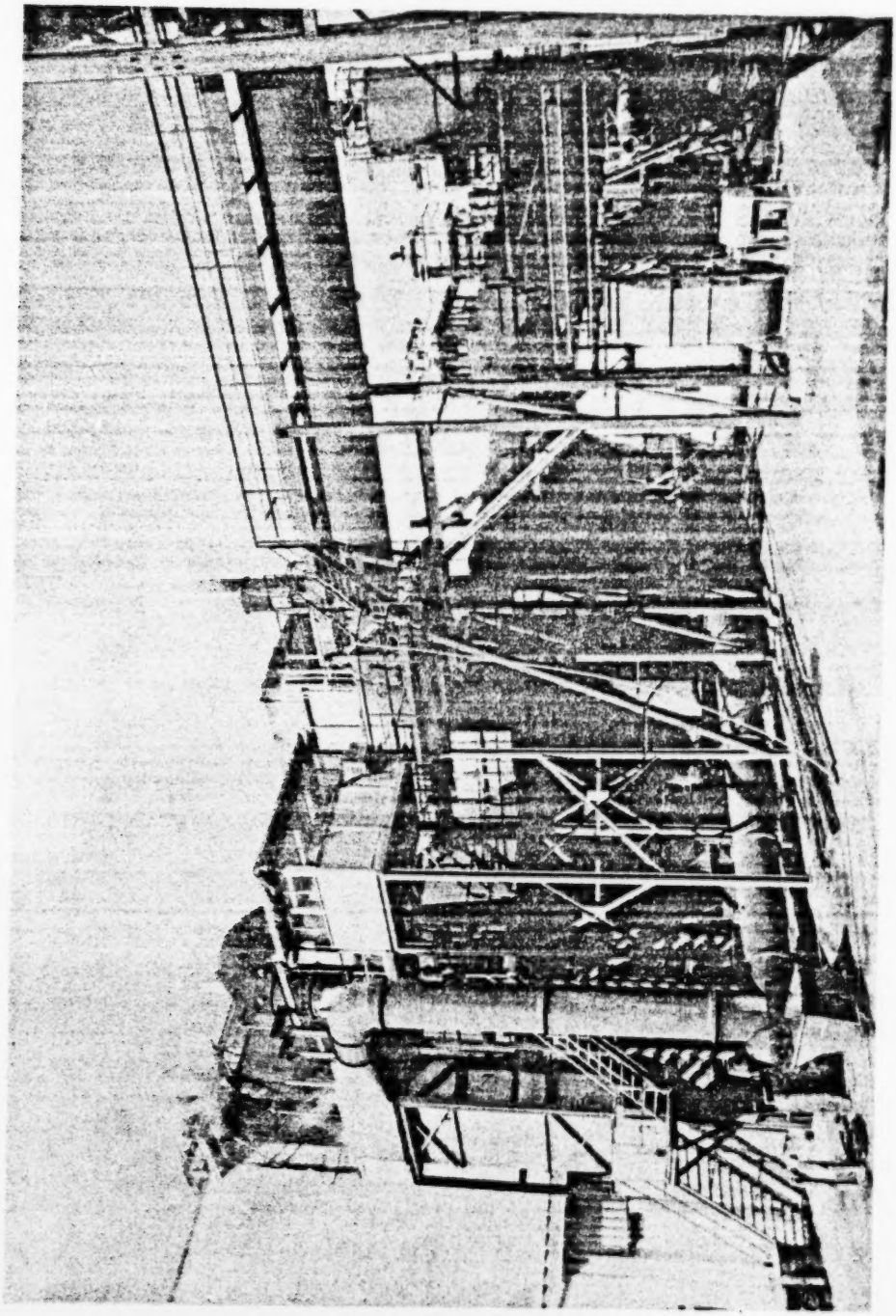


FIGURE 6-12

The objective of this program is to provide a broad evaluation of sorbent injection technology on a small tangentially fired boiler. The program provides a flexible utility-scale test facility to evaluate and optimize a range of sorbent injection alternatives. The program will provide support for the demonstration program and will help foster subsequent commercial development. The specific objectives are to:

1. Provide a utility-scale boiler which can be operated as a "research tool" over a range of operating conditions, with several coals, sorbents, and sorbent injection schemes.

2. Define the specific sorbents and injection technologies with the potential for achieving sulfur capture goals at minimum total cost.

3. Evaluate these technologies over a wide range of conditions representative of U.S. utility boilers. This includes optimization of process parameters and evaluation of sulfur capture, sorbent utilization, impacts on power plant components, and total cost.

4. Provide a data base which can be used directly by the utility industry to apply these technologies to meet projected emission reduction requirements at minimum total cost.

The program includes evaluations of three sorbent injection technologies. The initial field evaluations will involve upper furnace injection of a high-reactivity sorbent. The second and third field evaluations will be based on the status of technology at that time. Potential alternatives for these later evaluations are:

- promoted sorbents
- close-coupled pressure hydration
- humidification
- sorbent reinjection

The first series of field tests is scheduled for Summer and Fall of 1987. The second series of tests will be conducted in 1988, and the third series of tests will be conducted in 1989.

DEMONSTRATION PLANT PROGRAM

Combustion Engineering was recently awarded a contract by the U.S. EPA to conduct a sorbent injection demonstration program on a 180 MW tangentially fired utility boiler. The purpose of this program is to demonstrate significant reduction in sulfur oxides and nitrogen oxides emission levels at a fraction of the cost of add-on flue gas desulfurization systems, long-term boiler reliability at a level which existed prior to retrofit of the sorbent injection system, and cost-effective resolution of

potential technical difficulties attributable to sorbent injection operation such as additional slagging and fouling, changes in ash disposal requirements, and an increase in particulate load. The demonstration program will be conducted at a boiler designed by Combustion Engineering which has been operated continuously since 1959, except for normal maintenance outages.

Based on an evaluation of the time/temperature profile of the boiler and EPA guidelines, greater than 50 percent SO_2 reduction is predicted using $Ca(OH)_2$ at a calcium/sulfur molar ratio of 2.5:1. The unit is significantly larger than the 65 MWe Richmond Power and Light unit to be used in the prototype program and is more typical of Combustion Engineering's tangentially fired utility units.

The demonstration program field testing will be supported by mathematical modeling and pilot-scale testing at KDL. These pilot-scale investigations will include aerodynamic flow modeling and testing at the BSF. These facilities will be modified to the configuration of the demonstration plant boiler. In addition, intermediate scale combustion tests will be conducted to evaluate the impact of sorbent injection on heat transfer surface fouling and erosion and to evaluate the effect of sorbent injection and SO_2 capture on electrostatic precipitator performance. The KDL program is scheduled to begin in late 1987. Testing in the field unit will begin in 1990 and continue through 1991.